REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-04-2007

2. REPORT TYPE
Final Report to Gernot Pomrenke

3. DATES COVERED *(From - To)*
01-07-2004 to 31-01-2007

4. TITLE AND SUBTITLE
Maskless lithography using surface plasmon enhanced illumination

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-04-1-0426

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Harvard College, President & Fellows of
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
United States Air Force, AFRL
Air Force Office of Scientific Research
875 N. Randolph Street, rm 3112
Arlington, VA 22203
Program Manager: Gernot Pomrenke

10. SPONSOR/MONITOR'S ACRONYM(S)
USAF, AFRL, AFOSR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A: unlimited

AFRL-SR-AR-TR-07-0287

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The ability of surface plasmon enhanced illumination (SPEI) devices to use visible wavelengths to expose photoresist with subwavelength features has been demonstrated and a manuscript is being prepared for submission to PNAS. The SPEI devices consist of a regular array of nanometric features in a metal/dielectric laminate device that transmit light via extraordinaty optical transmission (EOT) with a semicollimated beam of light. This beam of light is scanned across a photoresist coated wafer to expose the photoresist and create the desired pattern. In this project SPEI devices and probes were created, a nanoscale scanner was designed and fabricated, and photoresist was developed to determine the geometric properties of the beam of light emitted from these SPEI devices, and a system throughput study was prepared to assess the throughput of a SPEI system when incorporated into a stepper system. The fundamental feasibility of this approach has been demonstrated. Harvard's licensing office is currently in discussions with Zeiss to commercialize this technology for the semiconductor industry.

15. SUBJECT TERMS
photolithography, surface plasmons, sub-wavelength

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU		

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Original Objective for the Project was to develop surface plasmon enhanced illumination technology and incorporate it into a new scanning device that would deliver resolution that is well beyond what can be achieved with conventional optical lithography.

Current Status of the Technology and Accomplishments

- Probe fabrication method and fixtures developed (two probes are shown in figure 1). The probes are fabricated by (1) cone polishing a single mode optical fiber (2) coating the fiber with an adhesion layer of Cr (~4nm thick) and a 100nm thick layer of Au, (3) mounting the fiber on a custom fixture and placing it in the focused ion beam instrument where the apertures and/or annuli are milled. (Note: the arrays are not centered on the fiber because the cone polishing process does not always leave the fiber core concentric with the outside diameter of the fiber.) Two arrays are shown in the figure the one on the left will be used for lithography. The bulls' eye emits a single beam of light and a commercialized lithography device would consist of an array with ~30,000 of these devices fabricated onto an array of VCSELs.
- Precision scanning stage developed and integrated into a Nikon TE300 inverted microscope (these are shown in figure 2). The scanning stage completely replaces the stage that came with the TE300 microscope. It consists of a base made with Super Invar (a zero thermal expansion material) on which are mounted a piezo-electric x-y-z nanostage from Polytec PI for fine positioning of the probe relative to the sample in z, and scanning in x, y; and another piezo-electric stage from PI for gross (actually "less fine") positioning of the probe relative to the sample. A capacitive sensor is used for sensing the height of the probe above (z) the sample. Building the scanning stage on a microscope body provides for easier imaging that is quite helpful during development work. In a commercialized device the microscope body would be replaced with the scanning stage from a stepper.
- Geometric characteristics of the beam characterized have been determined and it has been shown that the light emitted from the surface plasmon enhanced illumination probe shows a high degree of collimation and that the probe can operate at a height (z) well beyond the near-field (usually considered to be between one quarter of the wavelength up to one half of the wavelength) up to at least one wavelength above the sample. This is a critically important consideration for commercialization because if the probe had to be in the near-field the mechanical complexity involved would result in a stepper that is hopelessly complex and expensive. As it stands, controlling the position and parallelism is difficult but achievable within the level of complexity associated with steppers.
- In collaboration with ETEC (division of Applied Materials) the proof of concept was demonstrated for the use of this technology with their multi-electron beam mask writing technology. In this use the surface plasmon enhanced illumination device was used to illuminate small areas of a photoemitter to "prefocus" the emitted electrons before the beams entered the electron optics. A significant benefit to this approach was the resulting simplification of the optical system due to relaxed beam positional stability. ETEC subsequently cancelled their mask writer development project.
- Harvard is currently funding continuing development of the technology.

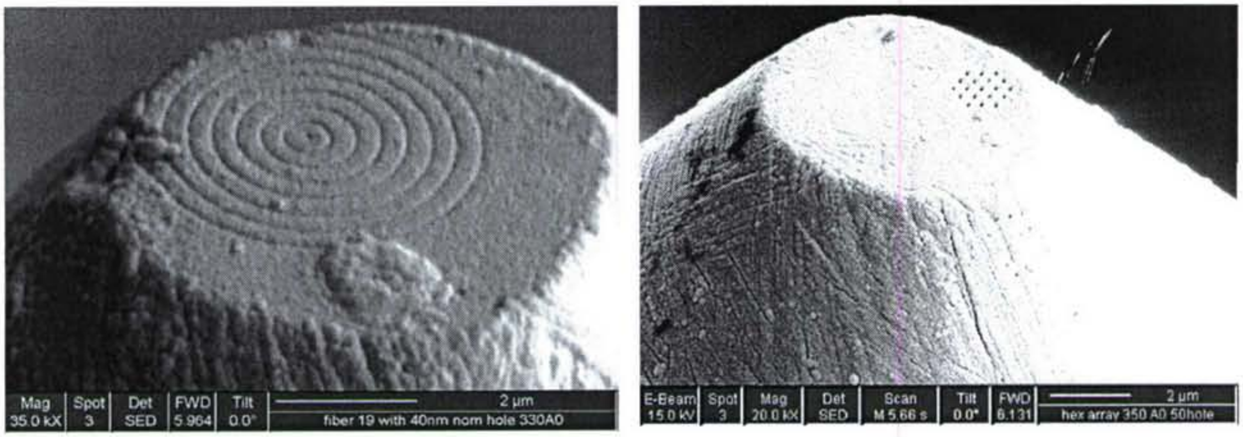

Figure 1. Nanohole array probes exhibiting extraordinary optical transmission of light with a high degree of collimation. Left: a bull's eye target that emits a single beam of light. Right: A hexagonal array of nanometric apertures that emit an array of beams of light. Both probes are scanned across a sample to excite fluorescence in the sample which is collected in transmission mode. These data are then incorporated into a composite image whose resolution is well below the wavelength of the light.

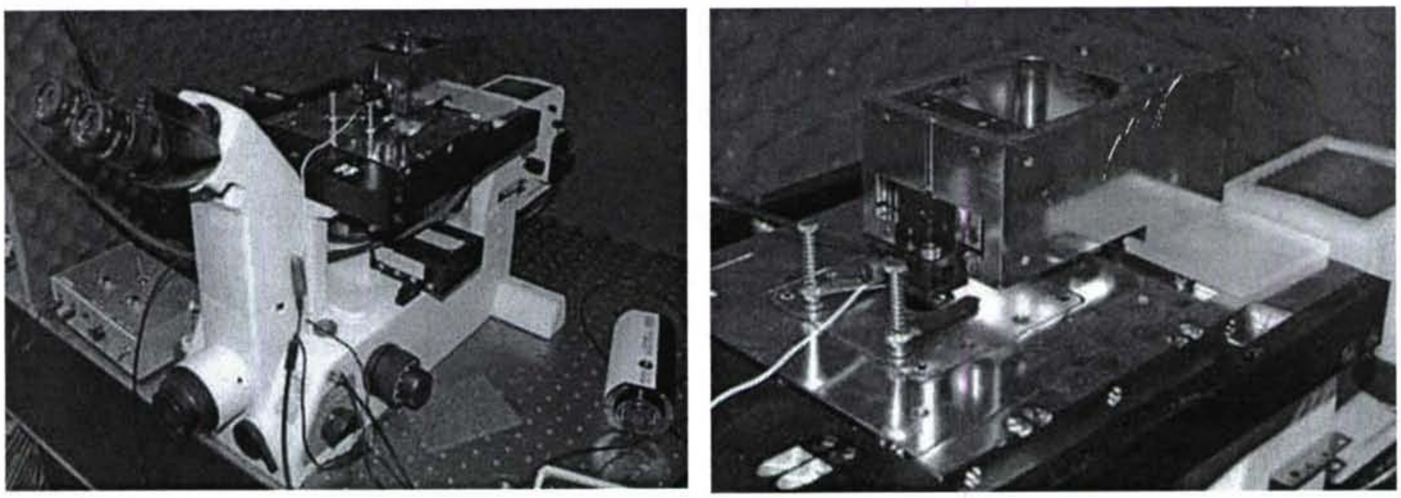

Figure 2. Left: The TE300 inverted microscope with the scanning stage incorporated. Right: A closeup of the scanning stage. The piezo electric stages are the polished pieces and the super Invar is black.

Next Steps:

1. Fabricate new probes based on the current knowledge of this technology derived from the characterization of the geometric properties of the emitted light.
2. Integrate the new probes into the scanning stage and write patterns in photoresist.

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Researchers supported during this grant:

- Dale Larson, the principal investigator
- Peter Stark
- Allison Halleck, and
- Linda Phinney (maiden name Rinko when supported on the p roject).

Publications[1-3]:

1. Maldonado, J. R., Coyle, S. T., Varner, J. K., Moore, R. C., Stark, P. R. H. & Larson, D. N. Preliminary evaluation of surface plasmon enhanced light transmission with a scanning 257nm ultraviolet microscope. J. Vac. Sci. Technol. B 22, 3552-3556 (2004).
2. Stark, P., Halleck, A. E. & Larson, D. N. Short order nanohole arrays in metals for highly sensitive probing of local indices of refraction as the basis for a highly multiplexed biosensor technology. Methods: Companion to Methods in Enzymology 37, 37-47 (2005).

.A manuscript is currently being prepared for submission to PNAS. I will forward the citation information to Dr. Pomrenke when it becomes available.